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Fatal Road Traffic Vehicle Collisions With Pedestrian Victims

Forensic Postmortem Computed Tomography and Autopsy Correlation

Vasiliki Chatzaraki, MD, Michael J. Thali, MD, eMBA, Garyfalia Ampanozi, MD, MSc, and Wolf Schweitzer, MD

Abstract: Fatal car-to-pedestrian collisions regularly appear in the forensic pathologist's routine, particularly in places of extended urbanization. Postmortem computed tomography has gained an exceptional role to supplement autopsy worldwide, giving information that is supplementary or complimentary to conventional autopsy. In this retrospective study, a total number of 320 findings in a series of 21 pedestrians fatally hit by cars and trucks of both postmortem computed tomography and autopsy were correlated. According to our results, it is best to combine both methods to give well-founded answers to questions pertaining to both collision reconstruction and cause of death.

Key Words: virtopsy, forensic radiology, postmortem computed tomography (PMCT), autopsy, pedestrians, traffic accidents and collisions

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Academic and practical impact of postmortem computed tomography (PMCT) imaging is rising since more than a decade.[1] Postmortem computed tomography proves already to be an excellent tool to a medicolegal autopsy by adding findings that may be missed or that are not visible at autopsy. It does have a distinct diagnostic profile that differs from the diagnostic profile of an autopsy,[2] whereby PMCT supplements rather than replaces the conventional method.[3,4] Nevertheless, the question of whether PMCT will be capable of displacing autopsy in the future has repeatedly been considered. It remains at the center of discussions within the forensic community.[5–7] Although natural death cases end up representing the largest portion of deaths in many countries,[3,8] violent deaths are a key category in most jurisdictions that use forensic pathology. In this context, it is notable that some open, unsolved, cold cases were addressed using PMCT.[9–11]

Currently and in our jurisdiction, pedestrians seem to represent one of the most common fatalities among the category of violent deaths.[12] With increasing population, increasing intermingled traffic and pedestrian volumes will associate with a relatively high number of traffic fatalities.[13] Depending on specifics of the vehicle hitting the pedestrian, each case contains different dynamics of impact and injury patterns. Pedestrians hit by cars and trucks, through a direct collision, by overrunning or both, mostly die of high severity blunt force polytrauma. Prior research suggested that PMCT provides relevant information supplementary to autopsy in blunt trauma injuries.[14]

The primary role of the forensic investigation is to determine manner and cause of death. This requires also the search for possibly preexisting morbidity, a test for possible drug or alcohol consumption, and to disambiguate, among the fatal derangements, if applicable, primary and secondary injuries of the person that was hit. Cause of death investigation in a medicolegal traffic examination serves the purposes of a joint medicolegal and technical forensic collision reconstruction.

Reconstructive relevance from the view point of the forensic pathologist pertains to morphology in context: correlating the postmortem findings with the collision, involving questions such as from where was the body hit, how did the vehicle affect the body, and how were the fatal injuries caused. These are typically very mechanical questions. Injuries concerning special regions of the body, like the neck, pelvis, and lower extremities joints, obtain an important role for car-to-pedestrian crashes reconstruction.[15–18] Patterned injuries may be particularly important.

Relevance to the cause of death builds on the assumption that a cause of death statement can, in fact, be formulated correctly, based on a morphological postmortem examination. Usually, the degree of affection or severity of trauma or pathology of a vital organ or its supplying structure needs to exceed known tolerances, or the expert opinion quickly risks becoming difficult. An absence of an easy agreed-on cause of death-related injury, though uncommon, is a particularly relevant problem in pedestrian traffic fatalities.

The manner of death may then be deemed to be accidental by the forensic pathologist, but a driver still may be charged with manslaughter or even homicide, and, despite absent proof of criminal misconduct under the penal law, a civil lawsuit may ensue. Hence, detailed documentation even in so-called "obvious" or "clear" cases is legally relevant.

The current aims of this study were to compare the diagnostic value of PMCT and autopsy and to understand better how both methods contributed to the evaluation of the group of pedestrian fatalities.

MATERIALS AND METHODS

A retrospective search of our institute's traffic fatalities of the last 6 years (October 2011–March 2017) identified 21 pedestrians who died after vehicle collisions and who were examined with PMCT and subsequent autopsy. Ten were male (age, 64.8 ± 23.03 years) and 11 were female (age, 70.5 ± 16.8 years). Thirteen (62%) comprised collisions with conventional passenger cars, 7 (33%) with trucks, and 1 (5%) with an electromobile car. Fifteen (71%) cases were pure collision incidents, either with or without evidence of a subsequent fall on the pavement. The remaining 6 (29%) were run over by the involved vehicle.

Initial survival time ranged from immediate death to 19 days. Approximately half (10; 48%) had undergone medical care after the collision. Medical care included resuscitation measures,

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transportation, hospitalization, and emergency surgery such as osteosynthesis, thoracotomy, or drainages.

All of the 21 bodies underwent whole-body PMCT. The time interval between death and PMCT ranged from 3 to 66 hours (28.3 ± 23.1 hours). The time between PMCT and autopsy ranged from 40 minutes to 70 hours (after removal of the 2 outliers of 40 minutes and 70 hours: 10.4 ± 10.3 hours). All bodies underwent a full autopsy.

All whole-body postmortem imaging was performed with bodies in a supine position. Imaging was performed on a 128-slice CT scanner (SOMATOM Definition Flash; Siemens Healthineers, Erlangen, Germany). Imaging parameters were as follows[19]: tube voltage, 120 kVp, and slice collimation, 128 × 0.6 mm. All scans were performed using automatic dose modulation software Siemens CARE Dose 4D (CARE Dose 4D; Siemens Healthineers). Scans were reconstructed at 1- or 2-mm slice thickness. Detailed PMCT image reconstructions were also obtained from the head and neck, as well as the thorax and abdomen,[19] with a slice thickness of 1.0 mm and an increment of 0.6 mm, using both soft and hard kernel reconstructions.

Routine reading of PMCT had been performed either by board-certified pathologists and radiologists or by radiology or forensic pathology trainees in cooperation with board-certified specialists. Each PMCT had been presented and discussed at the institute's daily case review panel, and also correlated with the autopsy results considered at the autopsy review panel discussion, after each autopsy. All cases were documented with formal written radiology reports and image catalogs for PMCT, extensive autopsy protocols, written expertise including ancillary tests, and a series of autopsy photographs.

For this study, review of these PMCT data, PMCT reports, and autopsy protocols data was performed by 2 readers, one forensic pathologist with 10-year and one resident with 9-month experience in postmortem forensic radiology. For discrepant opinions regarding diagnosis or diagnostic categories, a consensus was achieved.

After the evaluation of the data of all the cases studied, 320 morphological changes were identified as relevant in total and listed one by one. Of these, 259 were judged relevant to the reconstruction of the collision (n_R = 259), and 121 were seen as relevant for the cause of death (n_C = 121). There was an overlap because many of the findings were assessed as relevant to both collision reconstruction and cause of death determination. Afterward, search for the correspondent findings contained in autopsy protocols and macroscopic photographs took place. The autopsy findings were categorized according to the same process followed for the PMCT findings. As far as the data allowed, all data on PMCT, autopsy protocols, and macroscopy photographs were included in the review.

Findings of reconstructive relevance from a view point of a forensic pathologist included aspects such as indications regarding the direction of collision, indications to severe compression, or number of single blunt impacts. All findings were rated first for their reconstructive relevance and, subsequently, with regard to the relevance to a cause of death.

Furthermore, the findings were categorized into 3 classes, based on practical experience and based on recommended autopsy practice[20]: class 1 (routinely examined with technical ease at autopsy), class 2 (moderately hard to access or identify), and class 3 (very hard to access or identify) based on routine experience. In the reconstructive relevance group of diagnoses, class 1 contained cranial, laryngohyoid, clavicular, sternal and rib fractures, intracranial hemorrhages, and sternoclavicular or acromioclavicular luxations. Class 2 included brain stem injuries, fractures of the teeth, spinal fractures (except for the cervical part), soft tissue hemorrhages, and extremity fractures (first-impact "bumper" fractures included). Class 3 findings contained pharyngeal detachment, cervical spine fractures, scapular fractures and spinal cord injuries, and skeletal fractures of the pelvic bone, feet, and hand bones. For causes of death, typically easy-to-access examinations were categorized as class 1 and comprised most organs and tissues of the head, thorax, and abdomen; brain stem and spinal cord injuries and atlanto-occipital or cervical spine luxation were categorized as class 2, whereas class 3 diagnoses (ie, hard to diagnose at autopsy due to technical aspects of standard forensic dissection procedure) relevant to cause of death considerations were severe pharyngeal lesions, pneumothorax, and pneumothorax with mediastinal shift.

Then, findings were classified as belonging to the skeletal system or as belonging to the soft tissues and organ category for reconstruction relevance. For cause of death relevance, findings were classified into 3 categories as belonging to the skeletal system, soft tissue and organ findings, and findings of body cavities, because potentially fatal gas accumulations are not pure organ findings.

Their presence and detectability were checked in PMCT protocols and autopsy protocols. Deliberately chosen single points were awarded for scoring the identified features. However, no weighting was used. Each finding was scored either with 1 or 0. Scores were awarded twice—once for each examination method—depending on the presence or the absence of the respective finding in PMCT and in autopsy documentation, respectively (ie, a finding detected only in PMCT but not by autopsy was scored with 1 point for PMCT and 0 points for autopsy). Eventually, PMCT and autopsy methods were characterized by 2 total score numbers each, one for identifying morphological changes that had reconstructive relevance and one score for identifying morphological changes that were identified as relevant to the cause of death.

The results were summarized in tables and scored in both relevance categories for both PMCT and autopsy. Excel (Microsoft Excel; Microsoft Corporation, Redmond, WA) was used for tables and creating graphs of the study data.

RESULTS

Overall, morphological changes with reconstructive relevance, that is, with relevance to the collision reconstruction, were more often identified in PMCT than at autopsy. This result does not imply, however, that critical or important findings were not missed at PMCT: some findings of reconstructive relevance were partial to autopsy detection, such as soft tissue injuries. Conversely, findings that bore relevance to the cause of death were more often found at autopsy. However, some cause of death diagnoses could only be made with PMCT, such as tension pneumothorax.

TABLE 1. Overall Case-Based Performance of Methods for Both Reconstructive and Cause of Death Relevant Findings

	Reconstructive Relevance	Cause of Death Relevance
PMCT better	12 cases	3 cases
PMCT and autopsy equal	4 cases	3 cases
Autopsy better	5 cases	15 cases

Relevance to Collision Reconstruction

Quantitative Evaluation

From all 21 cases, PMCT performed better than autopsies in 12 cases and autopsies performed better than PMCT in 5 cases. In 4 cases, both methods scored the same (Tables 1 and 2).

From the 259 (100%) reconstructive relevant findings of all of the 21 cases, 165 (63.7 %) were detected in both PMCT and autopsy. Sixty findings (23.2 %) were detected only by PMCT and 34 (13.1 %) only by autopsy (Table 2, Fig. 1).

Qualitative Aspects

Injuries related to primary impacts (where the vehicle struck the pedestrian first), skeletal fractures (Fig. 2) and joint luxations in all body regions, as well as injuries of the brain, brain stem (Fig. 3), spinal cord (Fig. 4) and soft tissue gas accumulations were detected by PMCT.

Postmortem computed tomography typically missed only a few score points by not detecting soft tissue hemorrhages, skin abrasions, or soft tissue defects (Fig. 5), although these findings display high importance for such cases. In one case, PMCT did not exhibit a brain stem injury because of severe reconstruction artifacts originating from metallic dental restorations and the bones of the cervical spine. In a second case, PMCT missed brain contusions because of insufficient contrast and spatial resolution relative to their small size. In another 2 cases, PMCT failed to reveal torn cervical spine ligaments due to what appeared to be a nondislocated atlanto-occipital luxation.

Autopsy scored lower in comprehensively detailing skeletal fractures. For example, autopsy was capable of proving the presence of some skeletal injuries but failed to document others,

TABLE 2. Scores Pertaining to the Reconstructive Relevant Findings for PMCT vs Autopsy

Reconstruction Relevant Findings	PMCT Score	Autopsy Score	PMCT, %	Autopsy, %	Total	PMCT and Autopsy	Only PMCT	Only Autopsy
Primary impact	18	17	100	94.5	18	17	1	—
Cranial and facial fractures	18	14	100	77	18	14	4	—
Brain and brainstem injuries	4	6	66	100	6	4	—	2
Epidural hemorrhage	1	1	100	100	1	1	—	—
Subdural hemorrhage	6	6	100	100	6	6	—	—
Subarachnoid hemorrhage	9	9	100	100	9	9	—	—
Teeth fractures	1	1	100	100	1	1	—	—
Pharynx detachment	1	1	100	100	1	1	—	—
Laryngohyoid fractures	2	2	100	100	2	2	—	—
Cervical spine injuries	8	6	100	75	8	6	2	—
Atlanto-occipital luxation	1	3	100	33	3	1	—	2
Sternoclavicular luxation	2	2	100	100	2	2	—	—
Acromioclavicular luxation	1	1	100	100	1	1	—	—
Thorax deformation	2	2	100	100	2	2	—	—
Clavicle fractures	2	0	100	0	2	—	2	—
Scapula fractures	6	2	100	33	6	2	4	—
Sternum fractures	7	6	100	86	7	6	1	—
Rib fractures (multiple)	19	14	100	73	19	14	5	—
Spinal cord injury	2	2	100	100	2	2	—	—
Lung contusions	6	6	100	100	6	6	—	—
Thoracic and lumbar spine	16	7	100	43.7	16	7	9	—
Pelvic fractures	11	4	100	36	11	4	7	—
Soft tissue hemorrhages	20	36	55	100	36	20	—	16
Monocle hematoma	1	3	33	100	3	1	—	2
Skin abrasions	5	14	35	100	14	5	—	9
Soft tissue defects	12	13	92	100	13	12	—	1
Degloving	0	2	0	100	2	—	—	2
Soft tissue emphysema	9	0	100	0	9	—	9	—
Upper arm fractures	4	1	100	25	4	1	3	—
Forearm fractures	3	1	100	33	3	1	2	—
Hand fractures	2	1	100	50	2	1	1	—
Hip joint luxation	2	2	100	100	2	2	—	—
Thigh fractures	3	2	100	66	3	2	1	—
Knee joint luxation	1	1	100	100	1	1	—	—
Leg fractures	15	8	100	53	15	8	7	—
Ankle joint luxation	3	3	100	100	3	3	—	—
Foot fractures	2	0	100	0	2	—	2	—
Total	225	199			259	165	60	34

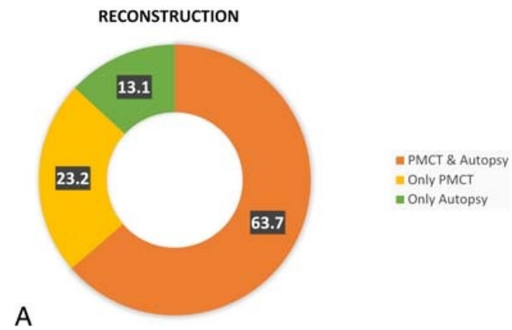

FIGURE 1. Overall case-based detection of the relevant to reconstruction (A) and to cause of death (B) findings in both PMCT and autopsy. Figure 1 can be viewed online in color at www.amjforensicmedicine.com.

especially located in more difficult to access body regions. These pertain to the facial bones, shoulders, cervical spine, pelvis, hand, or feet. Autopsy also lost score points by not detecting reconstructively relevant traumatic gas accumulations in soft tissues (soft tissue emphysema; Table 2).

Of the 18 primary impacts detected in PMCT, the typical wedge-shaped Messerer tibial fracture was observed in one case in which the fracture had been already osteosynthetized with a metal plate. However, the forensic radiologists could determine the direction of the impact even after the operation, which seemed possible with considerably less reliability at autopsy without extensive subsequent steps such as removal of bone and maceration (Fig. 6). A so-called Messerer fracture cannot prove alone a primary impact direction with perfect reliability, because such fractures can be also caused by other types of dynamics and indirect forces.[21,22] The combination of fracture analysis with documenting soft tissue injury observed during external examination and soft tissue dissection is required for a comprehensive examination into the question of the direction of blunt force trauma in collision reconstructions (Fig. 7). Assessing fracture heights and matching the distances off the ground of suspected impact injuries of the body and impact defects on the involved vehicle, like

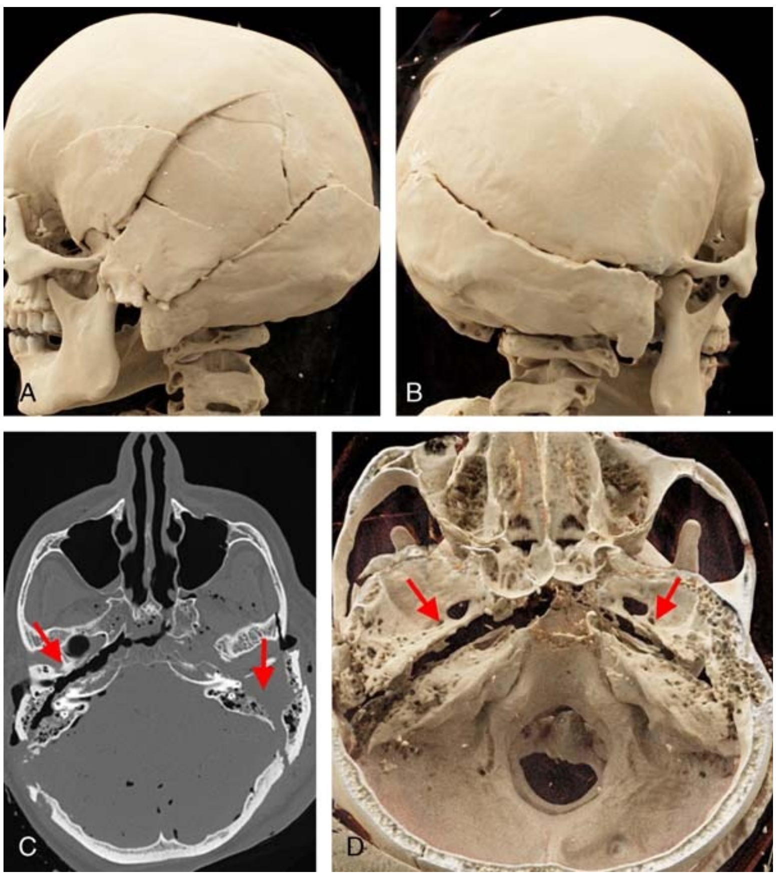

FIGURE 2. Reconstructive and cause of death relevance. Three-dimensional reconstruction of the skull with impression fracture of the left temporal and occipital bones (A) and ring fracture extended to the right occipital bone (B) and the cranium base with fractures of the sphenoid bone revealed in the axial slice through the skull in bone windowing (C) and in the 3-dimensional reconstruction with cinematic rendering (D). Figure 2 can be viewed online in color at www.amjforensicmedicine.com.

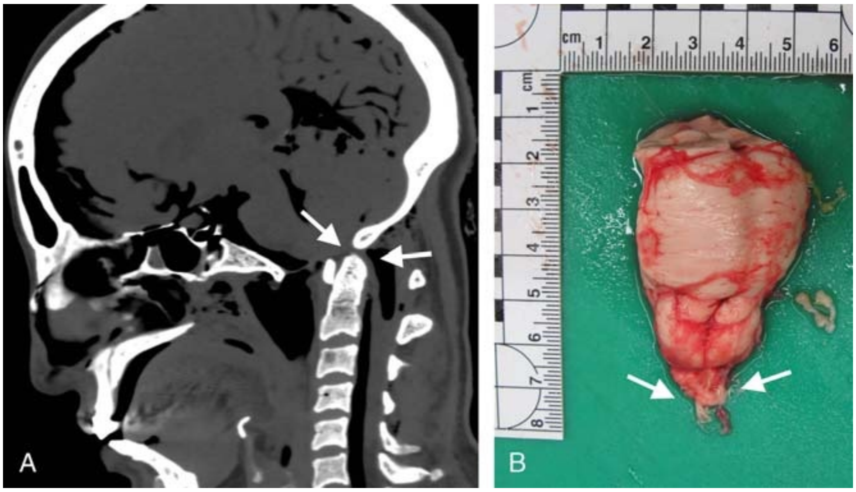

FIGURE 3. Reconstructive and cause of death relevance. A, Sagittal PMCT slice of the cranium and the cervical spine with dislocated atlanto-occipital luxation and brain stem injury (white arrows). Pneumocephalus is also noticed. B, Autopsy finding of brain stem transection (arrows). Figure 3 can be viewed online in color at www.amjforensicmedicine.com.

bumper damages, also allowed for suggesting relevant aspects for reconstructing a collision event.[23]

In 5 cases, PMCT did not document relevant skin and subcutaneous soft tissue injuries in contrast to the external examination of the corpse and the autopsy. In the cases where both methods scored similarly well, PMCT lost points by low sensitivity in soft tissue injuries but replaced the deficit with points autopsy lost by missing out skeletal injuries and gas collections.

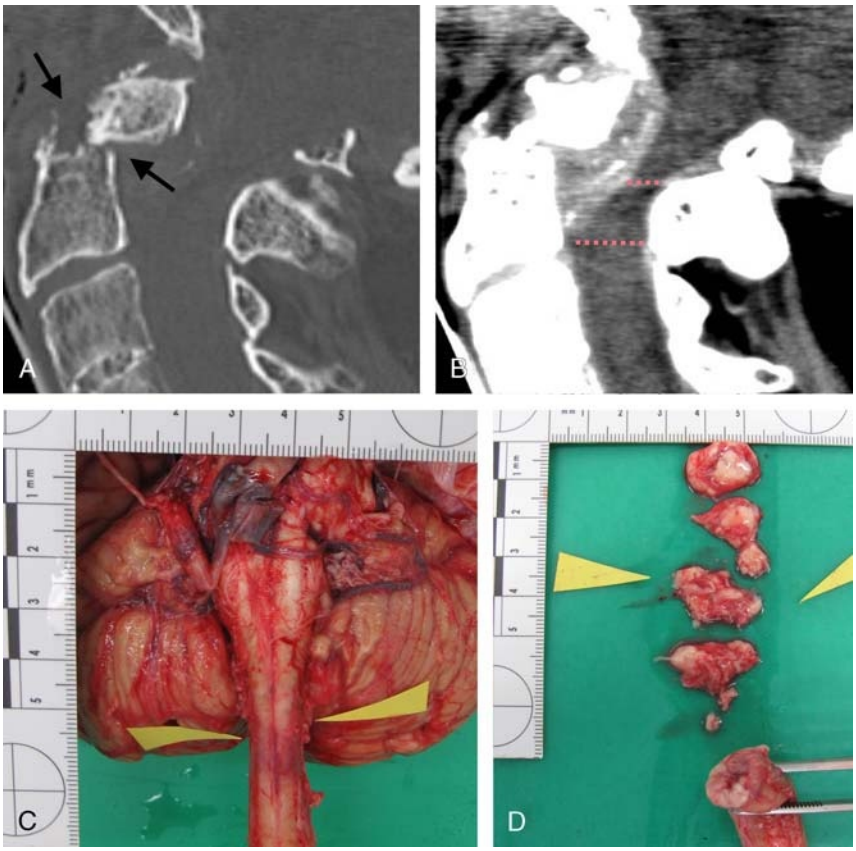

FIGURE 4. Reconstructive and cause of death relevance. Sagittal PMCT slices of the upper cervical spine in bone (A) and soft tissue window (B) and images of the spinal cord during autopsy (C, D). Spinal cord compression (B) caused by hyperextension trauma and dislocated fracture of the dens (A, arrows). B, The width difference of the spinal cord between the compressed—cranial and the intact area—caudal is also noticed (dashed lines). C and D, Spinal cord contusion with hemorrhage in the area of compression. Figure 4 can be viewed online in color at www.amjforensicmedicine.com.

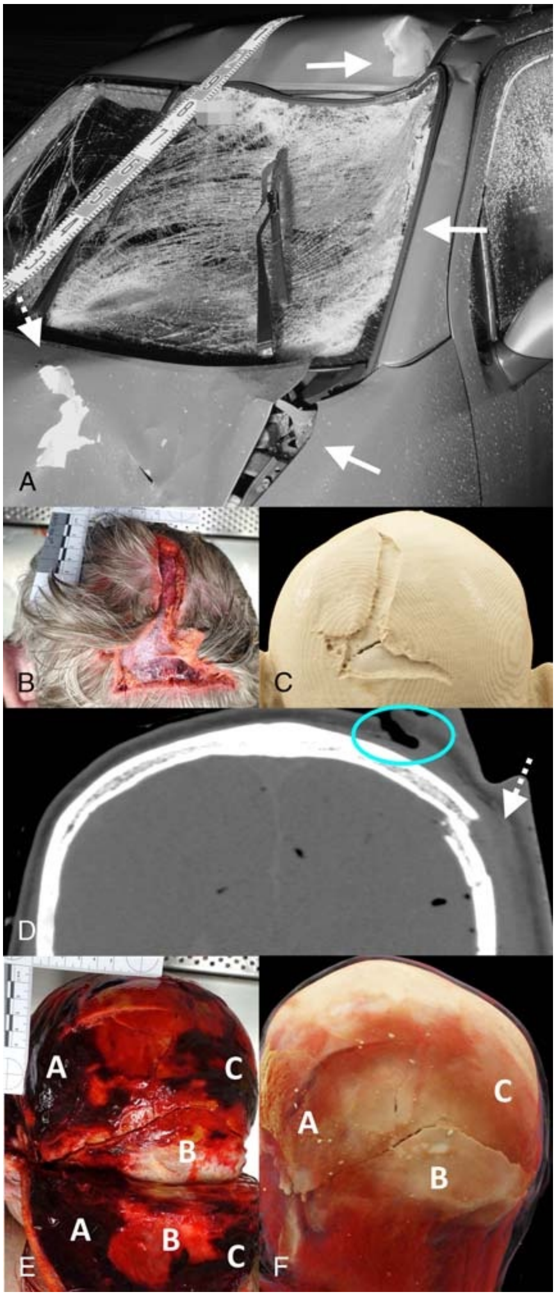

FIGURE 5. Reconstructive relevance. A, Image of the car involved in a case of fatal car-to-pedestrian collision with the pronounced damages of the hood and the widescreen corresponding to the secondary collision with the left side of the body and of the left front roof corresponding to the contact point with the victim's head (white arrows). Large L-shaped scalp laceration at the back of the head during the external examination of the deceased (B) and in 3-dimensional PMCT reconstruction (C). D, Coronal PMCT slice of the skull with soft tissue defect of the left galea (blue circle) correspondent to the scalp laceration of images B and C. Hematoma of the left temple adjacent to the skull fracture is also noticed (white dashed arrow). Ring fracture of the skull with the temporal, parietal, and occipital bones of the left side involved and with adjacent galeal hematoma during autopsy (E) and in 3-dimensional PMCT reconstruction (F; A–C indicate the same scalp areas, respectively). Figure 5 can be viewed online in color at www.amjforensicmedicine.com.

Cause of Death Relevance

Quantitative Evaluation

Across all 21 cases, PMCT performed better in only 3 of them, autopsy was better in 15 of them, and both methods scored the same in 3 cases (Table 1).

As opposed to reconstructive relevance, autopsies dominated the score for cause of death, identifying 110 relevant features compared with PMCT with 94 (Table 3).

From the 121 (100%) findings relevant to a cause of death of all 21 cases, the 83 (68.6 %) were detected by both methods, 11 (9.1 %) only in PMCT, and 27 (22.3 %) only during autopsy (Table 3, Fig. 1).

Qualitative Aspects

Autopsy led the way covering diagnoses such as pulmonary fat embolism (with a single one case with histological diagnosis of Falzi III degree fat embolism and fat layers in the pulmonary trunk detected in preautopsy PMCT; Fig. 8), cervical spine ligamentous injuries (atlanto-occipital dislocation in Table 3), nervous system injuries including a brain stem injury, fatal blood loss (exsanguination) such as pale organs, shock liver or subendocardial hemorrhages,[26] and important heart pathologies like myocardial infarction, cardiac contusions or coronary artery thrombosis.

FIGURE 6. Reconstructive relevance. Wedge-shaped tibia fracture with wedge pointing from the left against the inner side of the lower right leg after osteosynthesis during the survival period of the victim before death (A) and the correspondent large skin abrasion during the external examination of the body (B). A, Wedge shape and soft tissue injury both indicate the impact in a direction shown by the arrows. Figure 6 can be viewed online in color at www.amjforensicmedicine.com.

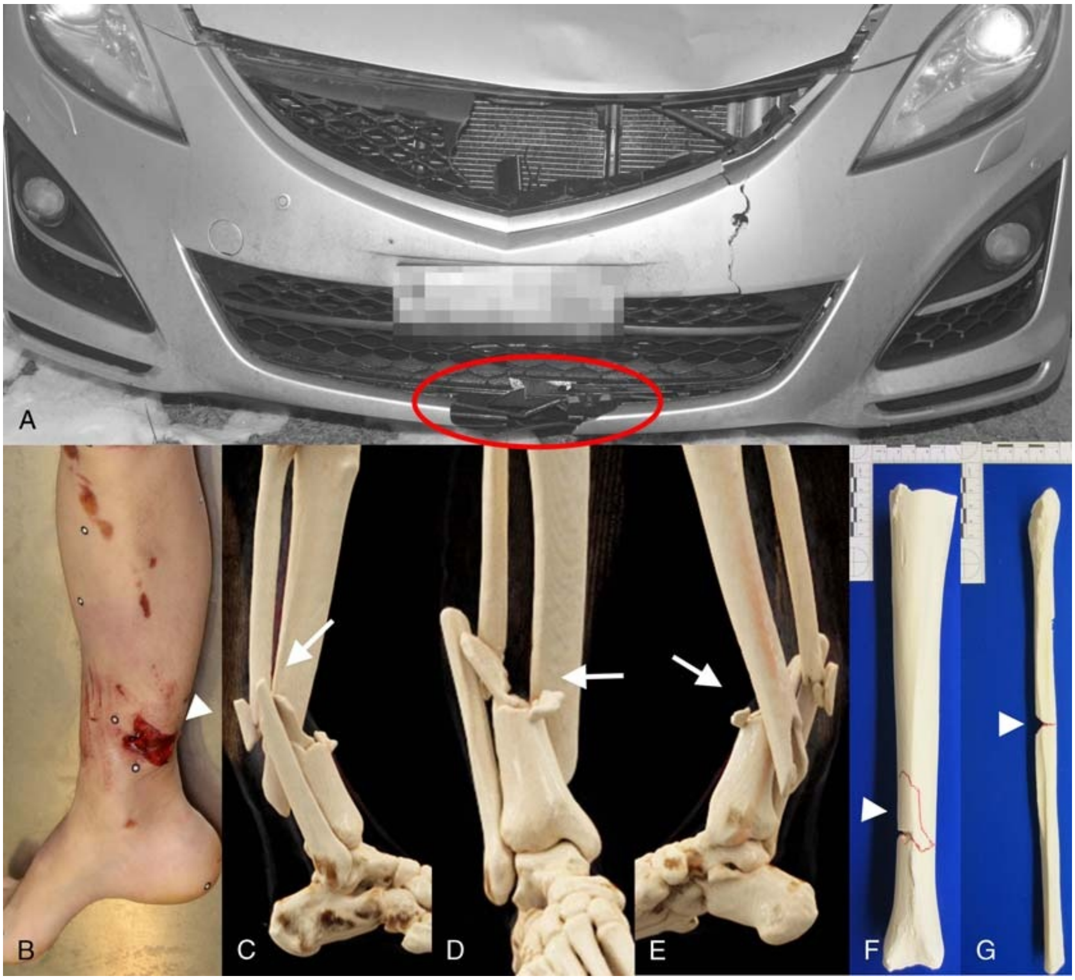

FIGURE 7. Reconstructive relevance. A, Image of the car involved in a fatal car-to-pedestrian collision with the front bumper damages of a low-cut sport bumper (red circle) corresponding to the primary impact. B, Soft tissue defect of the right inner lower leg adjacent to the ankle joint at the same above-ground level, with the bumper damages indicative of the first impact injury. Wedge-shaped fracture of the right tibia and fibula in the same area matching the direction of the vehicle against the pedestrian victim at the time of the primary impact as suggested by the skin and soft tissue findings (arrows, C–E: PMCT 3D reconstructions of the leg fractures) and real bone reconstruction of the tibia and fibula fractures (F–G) in back-right view after maceration. The vehicle seems to have affected the inner side of the right lower leg coming from a right–back direction in relation to the upright going pedestrian crossing the street vertical to the driving direction of the car. Figure 7 can be viewed online in color at www.amjforensicmedicine.com.

In the domain of relevance to the cause of death, autopsy failed to reveal internal life-threatening gas accumulations, that is, pneumothoraces with or without mediastinal shifts, pneumopericardium (Fig. 9), and some bone fractures in hard-to-dissect anatomical regions that were able to cause fat embolism.

Only in 3 cases, PMCT managed to perform better in determining a cause of death. These cases showed gas accumulations that autopsy could not detect in the absence of other, possibly concurrent cause of death findings.

Comparing PMCT and Autopsy Scores in Context of Technical Aspects

In our data, detection rates for findings that are difficult to dissect, reach, or examine at autopsy indeed correlated with lower autopsy detection rates (Tables 4 and 5). Detection rates in the context of the tissue category were also compared (Tables 6 and 7). For findings related to accident reconstruction, PMCT seems to be much better with hard-to-reach regions, especially to skeletal trauma, whereas autopsy predominates in the soft tissue and organ findings. For findings relevant to the cause of death, the distribution is not the same: autopsy deteriorates with harder-to-reach bodily regions, whereas predominates in revealing soft tissue and organ findings better than PMCT. On the other hand, PMCT provides very high sensitivity for body cavity findings because autopsy lacks in gas accumulation assessment.

DISCUSSION

The question of this study was to determine how both methods contribute to the evaluation of the group of pedestrian victims.

The results show that concerning detailed single-autopsy findings, PMCT proves to be an excellent supplementary tool to conventional autopsy adding information that is missed out or is not visible with a standard forensic autopsy. It is with good reason that nowadays, and as a global trend, PMCT is used increasingly as a supplementary method before a forensic autopsy.[27]

TABLE 3. Scores Pertaining to the Findings Related to a Cause of Death for PMCT vs Autopsy

Cause of Death Relevant Findings	PMCT Score	Autopsy Score	PMCT, %	Autopsy, %	Total	PMCT and Autopsy	Only PMCT	Only Autopsy
Cranial fractures	18	18	100	100	18	18	—	—
Epidural hemorrhage	1	1	100	100	1	1	—	—
Subdural hemorrhage	6	6	100	100	6	6	—	—
Subarachnoid hemorrhage	9	9	100	100	9	9	—	—
Ventricular hemorrhage	5	5	100	100	5	5	—	—
Pharynx detachment	1	1	100	100	1	1	—	—
Cerebral edema	1	1	100	100	1	1	—	—
Brain, stem and spinal cord injuries	10	13	77	100	13	10	—	3
Brain vessels and nerves contusion	0	1	0	100	1	—	—	1
Atlanto-occipital joint luxation	1	3	33	100	3	1	—	2
Cervical spine luxation	2	2	100	100	2	2	—	—
Skeletal fractures	6	4	100	67	6	4	2	—
Hemothorax	9	9	100	100	9	9	—	—
Pneumothorax	6	0	100	0	6	—	6	—
Mediastinal shift	2	0	100	0	2	—	2	—
Lung injuries	2	2	100	100	2	2	—	—
Increased lung radiotranslucency	1	1	100	100	1	1	—	—
Fat embolism	1	13	8	100	13	1	—	12
Subendocardial hemorrhages	0	3	0	100	3	—	—	3
Pericardial effusion	1	1	100	100	1	1	—	—
Pericardial injury	2	2	100	100	2	2	—	—
Pneumopericardium	1	0	100	0	1	—	1	—
Cardiac lacerations	0	1	0	100	1	—	—	1
Cardiac infarction – coronary artery thrombosis	0	2	0	100	2	—	—	2
Aspiration pneumonia	1	1	100	100	1	1	—	—
Liver lacerations	2	2	100	100	2	2	—	—
Spleen injuries	1	1	100	100	1	1	—	—
Renal injuries	1	1	100	100	1	1	—	—
Shock liver	0	1	0	100	1	—	—	1
Exsanguination	0	2	0	100	2	—	—	2
Aortic rupture	3	3	100	100	3	3	—	—
Soft tissue defects	1	1	100	100	1	1	—	—
Total	94	110			121	83	11	27

Comparison of single scores related to all relevant morphological observations in pedestrian fatalities, allowed for quickly identification of the fact that PMCT and autopsy have slightly different profiles. The question whether PMCT is capable of replacing autopsy during forensic investigations has already been considered and further discussed widely. Although both methods offered some overlap, better understanding of the differences is required.

Reconstructive Relevance

Regarding reconstructive features, according to the classification of the detection rates of both methods relative to the regions and their difficulties to be detected during a standard forensic autopsy, PMCT proves to be better in identifying reconstructive relevant findings located in hard-to-reach anatomical areas during an autopsy. Regarding tissue classification in reconstructive relevance, PMCT is better than autopsy in revealing skeletal findings as well as findings related to foreign bodies.[28] On the contrary, autopsies are better than PMCT in exposing soft tissue and internal organ pathology and trauma. Recently, this is improved with new visualization options.[29]

Postmortem computed tomography and autopsy both detected and documented brain hemorrhages, including coup and contrecoup injuries, laryngohyoid fractures, and luxations of main joints (hips, knees, ankles) and lung contusions. Superficial skin abrasions and subcutaneous fat tissue hematomas are seen mainly in external observation and autopsy but not so well in PMCT. It is already known that PMCT detects only a limited number of such injuries, mostly when they are sufficiently large.[30] The particular role that PMCT plays by capturing such injuries is to confirm the precise injury location for reconstructive considerations. As for the important reconstructively relevant patterned injuries originating from the collision with the vehicle, surface scanning and photogrammetry are the methods to use,[31–33] particularly because many traffic accident scenes and vehicles are increasingly 3-dimensionally scanned by forensic specialists.

Postmortem computed tomography failed to depict undislocated spine ligamentous injuries, but subluxations can indicate severe ligamentous and muscular injuries indirectly.[34,35] It dominated both in capturing trauma and pathology that is located in regions that are hard to access during autopsy.[35] Although autopsy can reveal facial or dorsally located spine fractures with a more extensive dissective approach, PMCT routinely

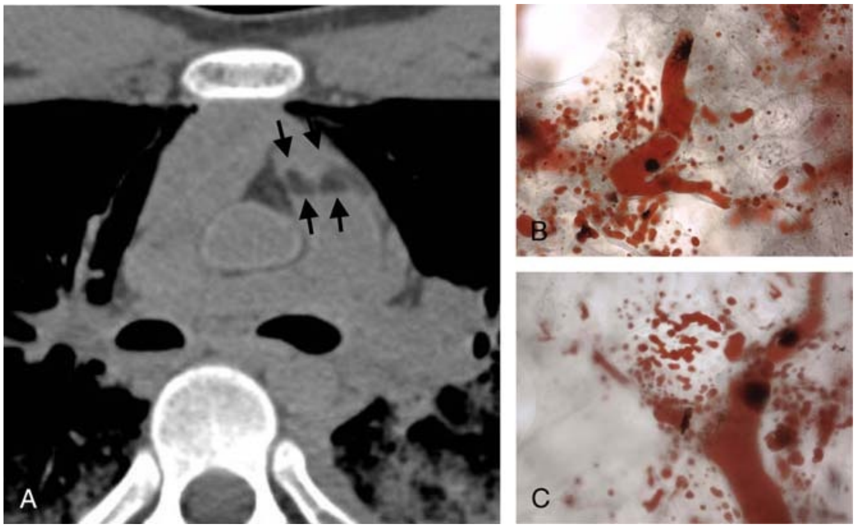

FIGURE 8. Cause of death relevance. A, Axial slice through the mediastinum in soft tissue windowing, with fat layers appearing in the pulmonary trunk indicating fat embolism. B and C, Diagnosis of III Falzi degree fat embolism was verified with double-edged Valentin's knife[24] specimen of the lungs obtained during autopsy and stained with Sudan Red[25] (scale, 100 μm). Figure 8 can be viewed online in color at www.amjforensicmedicine.com.

adds relevant information about facial and cervical spine fractures. The same stands for spine fractures in general, ribcage fractures, scapular fractures pelvic fractures—especially of the anterior lower pelvic rin—and fractures of the upper and lower extremities,[36] especially the hands and feet. On the contrary, subtle fracture hematomas are usually not depicted by PMCT.[27]

According to Heinemann et al[37] and Schmitt-Sody et al,[27] PMCT can also give valid answers to medicolegal questions concerning the precise location of any installed endotracheal intubation tubes or drainages in bodily cavities and aspects of osteosynthetic material placement. Such issues concern all of the handled medical cases during a forensic investigation, and it is of primary importance to also better investigate claims or suspicions of medical malpractice. Medical treatment concerns a considerable part of pedestrian fatality group (in our study, 48%), particularly because the survival time after the incident becomes larger. However, medical installations were not a focus of this study.

Relevance to Cause of Death

Postmortem computed tomography performs better than autopsy in the hard-to-reach regions. However, standard forensic autopsy remains better than PMCT in detecting cause of death relevant findings in the easy and medium difficulty levels of accessing bodily regions.

Regarding tissue classification, PMCT and autopsy are both useful for revealing skeletal injuries. Autopsy is better in revealing soft tissue and organ pathologies of cause of death relevance.

Findings containing cranial fractures and brain hemorrhages, brain edema, cervical spine injuries, hemothoraces, lung injuries, pericardial effusions and injuries, aspiration pneumonia, abdominal organ injuries, vessel lacerations, and soft tissue defects can be detected by both methods. Some brain stem injuries and some small brain parenchyma contusions and hemorrhages were not visible in PMCT because of CT reconstruction artifacts caused by dental or cervical spine bones, or because of their small size in combination with an already low CT contrast.[35]

Our study confirmed that nondisclocated atlanto-occipital joint luxation (ligamentous injuries) cannot be identified on imaging.[35]

Postmortem computed tomography scored in the field of cause of death examination through identifying and proving the presence of lethal gas accumulations, which autopsy cannot

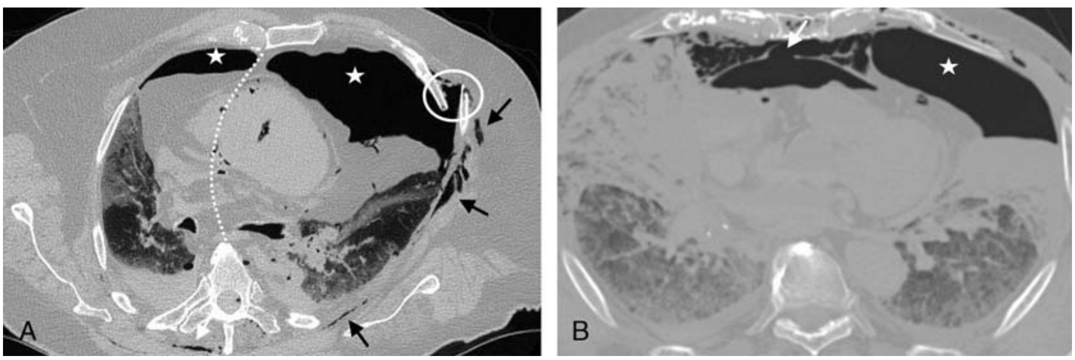

FIGURE 9. Cause of death relevance. A, Axial PMCT slices of the chest: gas accumulation in both thoracic cavities (asterisks, left > right), with mediastinal shift to the right (white dashed line) indicating tension pneumothorax on the left. B, Left pneumothorax (asterisk) and traumatic pericardial defect causing pneumopericardium (white arrow). Reconstruction and cause of death relevance: rib fracture on the left side (white circle) and soft tissue emphysema (black arrows) are also revealed.

TABLE 4. Detection of Accident Reconstruction Relevant Findings Comparing PMCT vs Autopsy in Correlation With the Easy (Class I), Medium (Class II), or Hard (class III) to Reach Anatomical Regions

Relevance for Reconstruction	Class I, %	Class II, %	Class III, %
PMCT	85 ± 31	92 ± 16	93.9 ± 20.2
Autopsy	89 ± 25	72 ± 31	59 ± 41

TABLE 6. Detection Rates of Accident Reconstruction Relevant Findings in Autopsy and in PMCT in the Context of Skeletal and Soft Tissue Categories

Relevance for Reconstruction	Skeletal Findings, %	Soft Tissue/Organ Findings, %
PMCT	97.2 ± 14	77 ± 33
Autopsy	67 ± 34	91 ± 27

deliver—in our study collectively, mainly with tension pneumothoraces, but from other studies, it is established that it also excels in documenting lethal gas embolism.[38]

Regarding possible causes of death, PMCT mostly fails in concise cardiac pathology and cardiac trauma. Although the same concerns the diagnosis of fat embolism, it is worth noting that this diagnosis is confirmed by forensic histology and not actually by autopsy.[39] Considering that in our facility, histological samples are collected, assessed, and graded during autopsy, the diagnosis of fat embolism was scored in this study as an autopsy finding. However, these histological samples can also be collected by minimal invasive forensic biopsy.[40]

Generally, however, PMCT fails to reveal sufficient morphological information about specific causes of death when compared with autopsies in pedestrian fatalities. On the other side, PMCT may indicate indirectly that such pathologies could come up in the autopsy or that they should be expected.

LIMITATIONS

First, the group studied seems to be relatively small (n = 21). An actual result of the collision reconstructions—for example, whether the victim was standing or not, from which direction, and where the victim was hit first—and a cause of death statistic might therefore only have limited strength. However, the strengths and weaknesses of PMCT vs standard forensic autopsy were examined by evaluating their respective performance across a total count of 320 single injuries.

Second, because of the retrospective character of this study, the forensic pathologists conducting the autopsies were not blinded to PMCT findings before autopsy. Consequently, hard-to-access regions or findings may be systemically documented by the forensic pathologists during autopsies because preautopsy PMCT indicated them to. Both PMCT and forensic autopsy were performed according to a standard routine. Were the study set-up as a neck-to-neck competition, or were one to maximize on findings by any means necessary, more score points could be achieved. A fully optimized PMCT will see all efforts be put into minimizing noise and artifacts, into maximizing resolution, possibly by scanning the body in several body positions and by using contrast agents to best advantage. A standard forensic autopsy, were one to improve complete coverage, would have benefit from a far more thorough inspection of what are hard-to-reach anatomical regions. This will include a detailed dissection of the whole spine, examination of the brain stem and spinal cord after removal as a whole (unless traumatically fragmented), and a detailed appreciation of all facial skull parts, the pelvic area, and the extremities to the last detail. Also, there will be full photographic documentation of all examined parts, comprising both positive and negative findings.

Last but not the least, it is relevant to point out that traffic fatality cases may pose histological, toxicological, or other laboratory analysis problems that are not part of the morphological appraisal of diagnoses pertaining to cause of death or collision reconstruction. However, that was not the focus of this study.

CONCLUSIONS

For optimal pedestrian-vehicle collision case documentation, our data show that it is best to combine PMCT and autopsy for reconstructive purposes, whereas PMCT performs astonishingly well even for identifying cause of death–related morphology in these cases despite not providing satisfying answers in what remain to be key domains of the autopsy. Qualitatively, both methods are unable to cover all aspects.

KEY POINTS

1. Twenty-one pedestrian fatalities hit by cars or trucks with overall 320 relevant findings to both accident reconstruction and cause of death in both PMCT and autopsy were retrospectively analyzed in the current study.
2. PMCT proved to perform better in the domain of reconstructive relevance in contrast to autopsy who dominated in detecting findings relevant to cause of death.
3. PMCT and autopsy, despite their great overlap, contribute with different profiles and roles in the forensic investigation.
4. Based on the results of this current study, the application of both methods is suggested, especially for the forensic investigation of road accidents including pedestrian fatalities.

TABLE 5. Detection of Cause of Death Relevant Findings Comparing PMCT vs Autopsy in Correlation With the Easy (Class I), Medium (Class II), or Hard (Class III) to Reach Anatomical Regions

Cause of Death Relevance	Class I, %	Class II, %	Class III, %
PMCT	73 ± 44	82 ± 29	100
Autopsy	95 ± 20	100	33 ± 57

TABLE 7. Detection Rates of Cause of Death Relevant Findings in Autopsy and in PMCT in the Context of Skeletal, Soft Tissue Organs, and Body Cavity Categories

Cause of Death Relevance	Skeletal Findings, %	Soft Tissue/Organ Findings, %	Body Cavity Findings, %
PMCT	83 ± 33	70 ± 45	100
Autopsy	91 ± 17	96 ± 20	50

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